LIFE CYCLE COSTS
AND
LIFE CYCLE SAVINGS
FOR
SOLAR WATER HEATING SYSTEMS

By

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The life cycle cost of a solar water heating system may be determined by the following equation[1]

$$LCC_S = C_I \cdot E_1 + (C_A \cdot A + C_B) \cdot E_1 + A \cdot C_O \cdot E_2 + C_M \cdot E_3 + (1 - F) \cdot L \cdot C_F \cdot E_4$$

Nomenclature:

LCC_S = Life cycle cost ($)
C_I = Initial cost of the conventional water heating system ($)
C_A = Collector area-dependent costs ($/ft^2), or ($/m^2)
C_B = Cost for pumps, valves, piping, etc., not strongly dependent on collector area
C_M = Maintenance costs in the first year ($)
C_O = Operating costs in the first year ($/ft^2 or $/m^2)
C_F = Fuel costs in the first year ($/MMBtu or $/GJ)
L = Annual heating load (MMBtu or GJ)
A = Collector area
F = Solar fraction (obtained from the solar energy factor in the OG-300 tables)
$E_{1, 2, 3, 4}$ = Economic factors that convert future cash flows to present value. (defined below)

The life cycle cost of a conventional (non-solar) heating system is given by

$$LCC_C = C_I \cdot E_1 + L \cdot C_F \cdot E_4$$

The life cycle savings are given by the difference between the life cycle costs:

$$LCS = LCC_C - LCC_S$$

$$= F \cdot L \cdot C_F \cdot E_4 - (C_A \cdot A + C_B) \cdot E_1 - A \cdot C_O \cdot E_2 - C_M \cdot E_3$$

The economic factors are calculated as follows:

$E_2 = PWF(n, r_o, d)$, where d=discount rate, r_o=operation cost inflation rate and n is the period of analysis
$E_3 = PWF(n, r_m, d)$, where r_m is the maintenance cost inflation rate
$E_4 = PWF(n, r_f, d)$, where r_f is the fuel cost inflation rate

For business applications, where expenses are deductible for tax purposes, the economic factors are multiplied by $(1 - t)$, where t is the effective federal-state income tax rate.

PWF is a present worth factor given, in general, by

$$PWF(n, r, d) = [1 - ((1 + r)/(1 + d))^n]/(d - r), \quad d \neq r$$

$$= n/(1 + r), \quad d = r$$

The factor E_1 accounts for the down payment, periodic mortgage payments, periodic property tax and insurance payments, income tax credits, and investment tax credits (for a business) and is calculated by

$$E_1 = \alpha - \beta - \sigma[(1+g)/(1+d)]^n + [(1-t)p+h] \cdot PWF(n,g,d) + (1-\alpha)[PWF(m,0,d)/PWF(m,0,i) - I] - B$$

where I = the cumulative present worth of income tax credits for interest payments and B is the cumulative present worth of depreciation tax credits. I is given by

$$I = t[PWF(m,0,d)/PWF(m,0,i) - PWF(m,i,d)/PWF(m,i,0)]$$

and, for straight line depreciation, B is calculated by

$$B_{SL} = t(1-\sigma) \cdot PWF(k,0,d)/k. \text{ where } k = \text{depreciation lifetime.}$$

For declining balance, B is calculated by

$$B_{DB} = t\delta \cdot PWF(k,-\delta/k,d)/k \text{ where } \delta = \text{declining balance multiplier,}$$

and for sum of years digits

$$B_{SOYD} = 2t(1-\sigma)[PWF(k,0,d)+(k-1-PWF(k-1,0,d)/d)]/(k(k-1)).$$

The remaining symbols are as follows:

α = downpayment (fraction of system cost)
β = investment tax credit fraction, if a business application
σ = fractional salvage value at end of equipment life
g = general inflation rate
p = property tax rate
h = insurance cost, as a fraction of system cost
m = period of mortgage
n = period of economic analysis

This method of economic analysis is essentially the same as the P_1, P_2 method in Reference (2).

The attached spreadsheet has been developed to perform the calculations. The following example illustrates the use of the spreadsheet.

Consider a residential (non-business) application of a SWH system on a new construction. The system will cost $5,000. The collector costs are $3,000 ($75/ft^2, 40 ft^2) and the remaining fixed costs are $2,000. The auxiliary system is electric with an initial energy cost of $0.11/kWh ($32.2/MMBtu). The annual delivered energy is 14.98 MMBtu (41045 Btu/day). The solar energy factor is 2. The following assumptions are made relative to the economic parameters: Maintenance cost($25), Operating cost ($0.375/ft^2), Discount rate (11%), Maintenance cost inflation rate (4%), Operation cost inflation rate (6%), Fuel cost inflation rate (10%), General inflation rate (4%), Property tax rate (3%), Insurance cost (0%), Down payment (10%), Mortgage interest rate (12%), Mortgage period (10 years), Salvage value (10%), Period of analysis (30 years). When these values are entered on the spreadsheet the result is a life cycle savings of $1555.

Now suppose that the SWH system is to go on a duplex and can be considered as a business. Also suppose straight line depreciation is selected. Then enter 2 in cell B52 and 1 in cell B53; the resulting life cycle savings are $2711.

References

(1) C. Dennis Barley and C. Byron Winn, "Optimal Collector Sizing by the Method of Relative Areas," *Solar Energy, Volume 21, pp 279-289, Pergammon Press, 1978.*

(2) J. Duffie and W. A. Beckman, *"Solar Engineering of Thermal Processes,"Second Edition, Wiley Interscience, 1991.*

Conventional system cost ($)	2000
Area-dependent cost ($/sq.ft.)	75
Other fixed costs ($)	2000
Maintenance cost (yr 1), ($)	25
Operating cost (yr 1), ($/sq.ft.)	0.375
Fuel cost (yr 1), ($/MMBtu)	32.2
Annual Heating Load (MMBtu)	14.981425
Collector Area (sq.ft.)	40
SEF(OG-300 tables)	2
Discount rate	0.11
Maintenance inflation rate	0.04
Operation cost infl. Rate	0.06
Fuel cost infl. Rate	0.1
Period of analysis (years)	30
General inflation rate (g)	0.04
Property tax rate (p)	0.03

Insurance cost (h)	0	
Downpayment (α)	0.1	
Investment tax credit (β)	0	
Salvage value (σ)	0.1	
Period of mortgage (m) (years)	10	
Depreciation lifetime (k) (years)	2	
Declining balance mult.(δ)	0	
Mortgage interest rate (i)	0.12	
Energy Factor (EF)	0.9	
Solar Fraction (F)	0.55	
PWF(n,ro,d), d unequal to ro	14.982	
PWF(n,ro,d),d=ro	28.302	14.982
PWF(n,rm,d), d unequal to rm	12.262	
PWF(n,rm,d), d=rm	28.85	12.262
PWF(n,rf,d), d unequal to rf	23.776	
PWF(n,rf,d, d=rf	27.273	23.776
PWF(n,g,d), d unequal to g	12.262	
PWF(n,g,d), d=g		12.262
PWF(m,0,d)	5.889	
PWF(m,0,i)	5.650	
PWF(m,i,d), d unequal to i	9.383	
PWF(m,i,d),d=i	8.929	9.383
PWF(k,0,d)	1.713	
PWF(k,δ/k,d)	1.713	
PWF(k-1,0.d)	0.901	
PWF(m,0,d)	5.889	
PWF(m,i,0)	17.549	
Effective tax rate (t)	0.300	9.383
I	0.152	
St. Line Depreciation	0.231	
Decl. Bal. Dep.	0.000	
SOYD Depreciation	1.411	0.706
α-β-σ[(1+g)/(1+d)]*n	0.086	
[(1-t)p+h]PWF(n,g,d)	0.257	
(1-α)[PWF (m,0,d)/PWF(m,0,i)-I]	0.801	
Business? (NO=1, YES=2)	1.000	
Depreciation Schedule (1,2,or3)	3.00	
Depreciation Factor (B)	1.411	
E1	1.144	
LCS	1555	